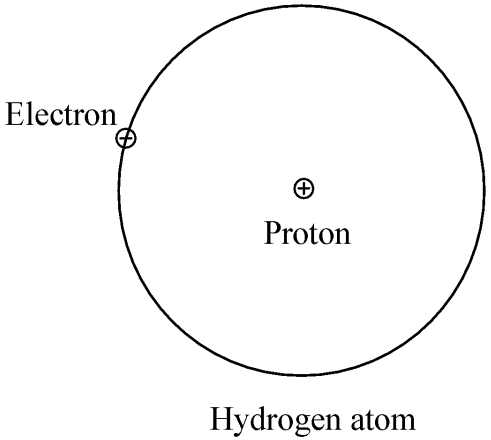
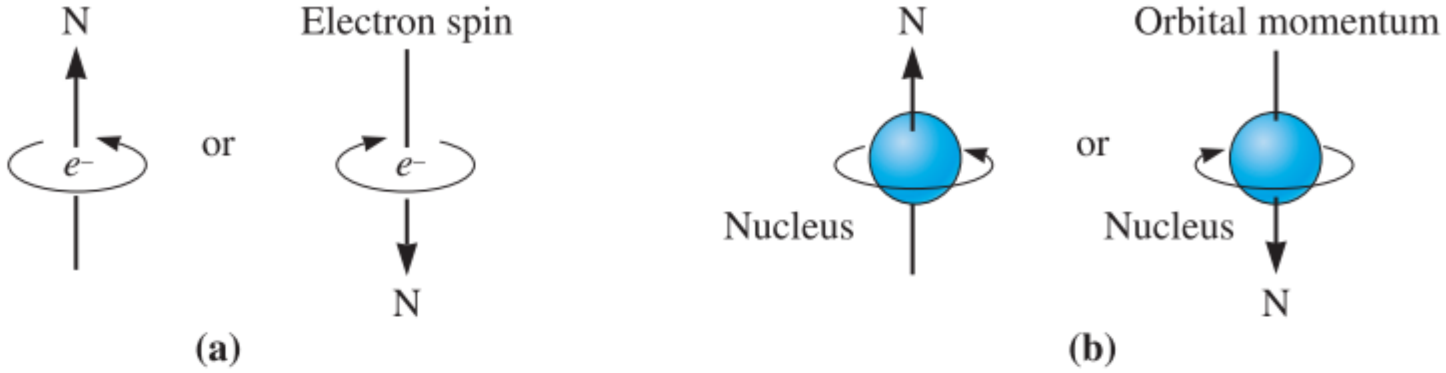
Magnetic Materials

MUSIC
alamy
www.alamy.com

12 B80919

Basic magnet





PERIODIC TABLE OF THE ELEMENTS

Key: 1 — Atomic number; H — Element symbol; Hydrogen — Element name; 1,008 — Atomic weight

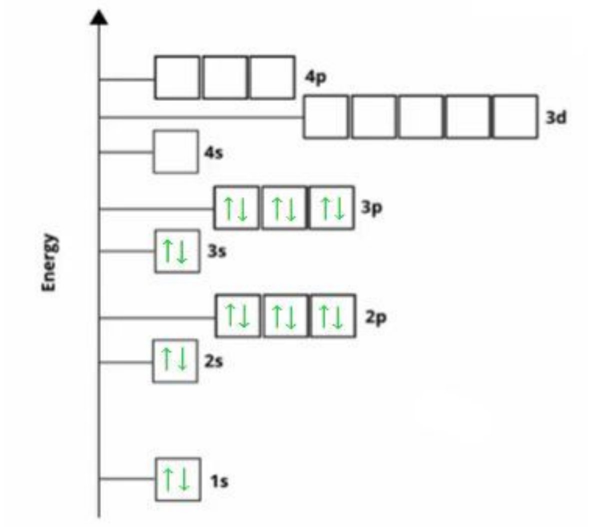
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1,008																	2 He Helium 4,003
3 Li Lithium 6,941	4 Be Beryllium 9,012											5 B Boron 10,811	6 C Carbon 12,011	7 N Nitrogen 14,007	8 O Oxygen 15,999	9 F Fluorine 18,998	10 Ne Neon 20,180
11 Na Sodium 22.990	12 Mg Magnesium 24,305											13 Al Aluminum 26,982	14 Si Silicon 28,086	15 P Phosphorus 30,974	16 S Sulfur 32,065	17 Cl Chlorine 35,453	18 Ar Argon 39,948
19 K Potassium 39,098	20 Ca Calcium 40,078	21 Sc Scandium 44,956	22 Ti Titanium 47,867	23 V Vanadium 50,942	24 Cr Chromium 51.996	25 Mn Manganese 54,938	26 Fe Iron 55,845	27 Co Cobalt 58,933	28 Ni Nickel 58,693	29 Cu Copper 63,546	30 Zn Zinc 65,390	31 Ga Gallium 69,723	32 Ge Germanium 72,640	33 As Arsenic 74,922	34 Se Selenium 78,960	35 Br Bromine 79,904	36 Kr Krypton 83,800
37 Rb Rubidium 85,468	38 Sr Strontium 87,620	39 Y Yttrium 88,906	40 Zr Zirconium 91,224	41 Nb Niobium 92,906	42 Mo Molybdenum 54,938	43 Tc Technetium 98,000	44 Ru Ruthenium 101,070	45 Rh Rhodium 102,906	46 Pd Palladium 106,420	47 Ag Silver 107,868	48 Cd Cadmium 112,411	49 In Indium 114,818	50 Sn Tin 118,710	51 Sb Antimony 121,760	52 Te Tellurium 127,600	53 I Iodine 126,905	54 Xe Xenon 131,293
55 Cs Cesium 132,906	56 Ba Barium 137,327	57 - 71 Lanthanides	72 Hf Hafnium 178,490	73 Ta Tantalum 180,948	74 W Tungsten 180,948	75 Re Rhenium 186,207	76 Os Osmium 190,230	77 Ir Iridium 192,217	78 Pt Platinum 195,078	79 Au Gold 196,967	80 Hg Mercury 200,590	81 Tl Thallium 204,383	82 Pb Lead 207,200	83 Bi Bismuth 208,980	84 Po Polonium 209,000	85 At Astatine 210,000	86 Rn Radon 222,000
87 Fr Francium 223,000	88 Ra Radium 226,000	89 - 103 Actinides	104 Rf Rutherfordium 261,000	105 Db Dubnium 262,000	106 Sg Seaborgium 266,000	107 Bh Bohrium 264,000	108 Hs Hassium 277,000	109 Mt Meitnerium 278,000	110 Ds Darmstadtium 281,000	111 Rg Roentgenium 282,000	112 Cn Copernicium 285,000	113 Nh Nihonium 286,000	114 Fl Flerovium 289,000	115 Mc Moscovium 290,000	116 Lv Livermorium 293,000	117 Ts Tennessine 294,000	118 Og Oganesson 294,000

57 La Lanthanum 138,906	58 Ce Cerium 140,116	59 Pr Praseodymium 140,908	60 Nd Neodymium 144,240	61 Pm Promethium 145,000	62 Sm Samarium 150,360	63 Eu Europium 151,964	64 Gd Gadolinium 157,250	65 Tb Terbium 158,925	66 Dy Dysprosium 162,500	67 Ho Holmium 164,930	68 Er Erbium 167,259	69 Tm Thulium 168,934	70 Yb Ytterbium 173,040	71 Lu Lutetium 174,967
89 Ac Actinium 227,000	90 Th Thorium 232,038	91 Pa Protactinium 231,036	92 U Uranium 238,029	93 Np Neptunium 237,000	94 Pu Plutonium 244,000	95 Am Americium 243,000	96 Cm Curium 247,000	97 Bk Berkelium 247,000	98 Cf Californium 251,000	99 Es Einsteinium 252,000	100 Fm Fermium 257,000	101 Md Mendelevium 258,000	102 No Nobelium 259,000	103 Lr Lawrencium 262,000

Magnetic moment of atom

- Unpair electron
- Electronic configuration of Ar atomic no 18
- Electronic configuration of Na atomic no 11

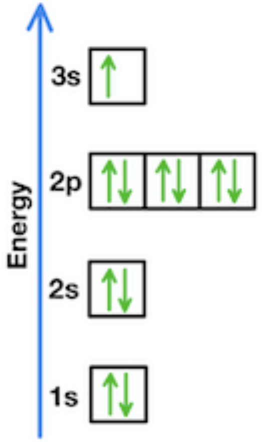
Electron Configuration vs Orbital Diagram



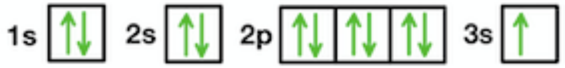
Sodium (Na):

11 electrons

$1s^2 2s^2 2p^6 3s^1$



OR



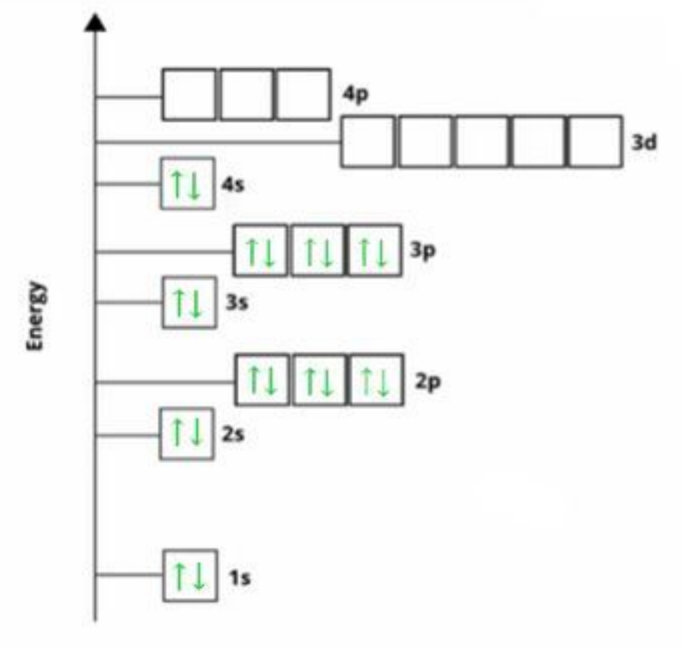
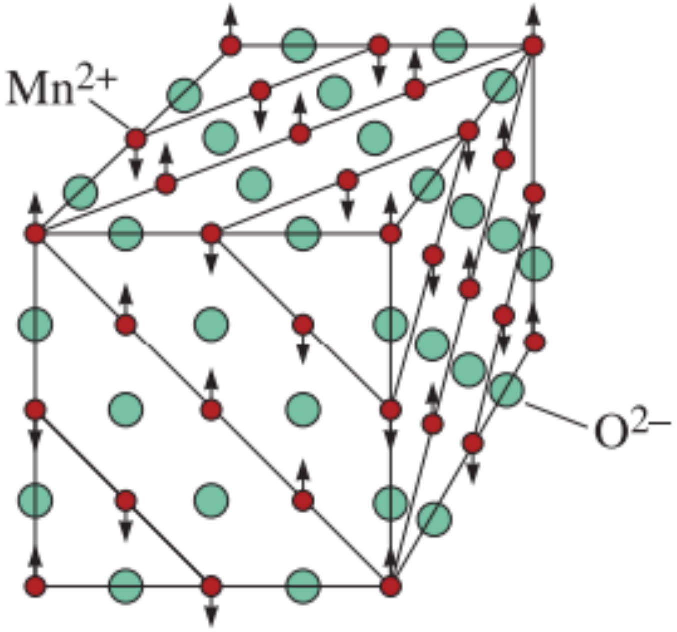


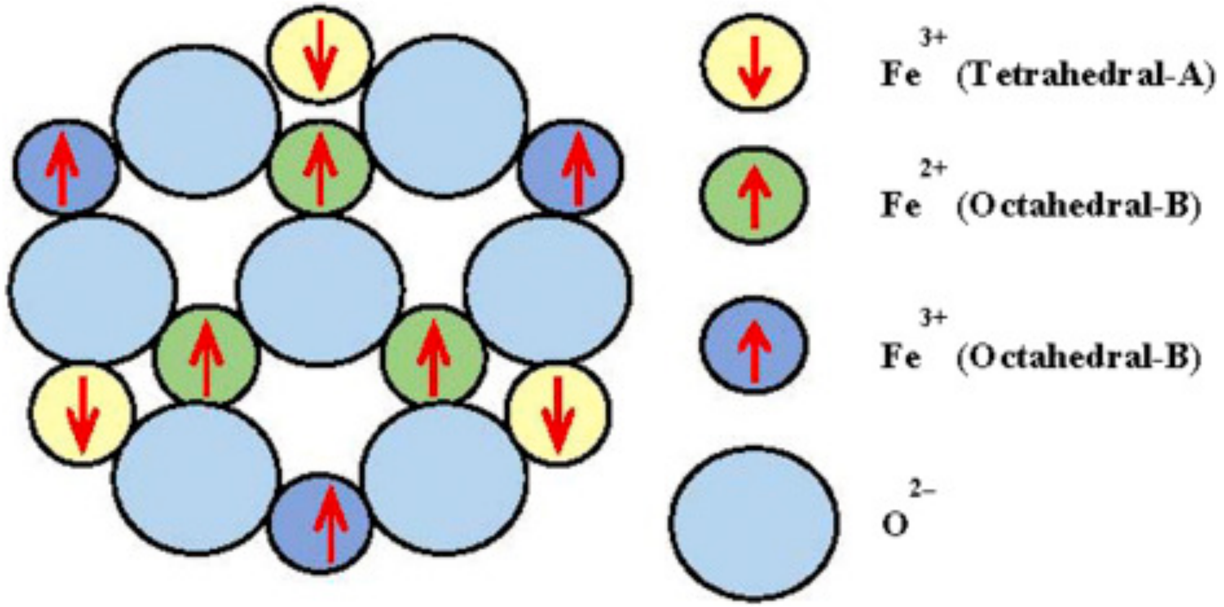
TABLE 20-1 ■ ***The electron spins in the 3d energy level in transition metals with arrows indicating the direction of spin***

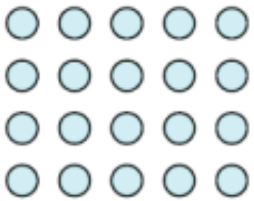
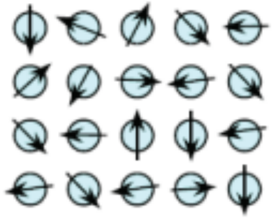
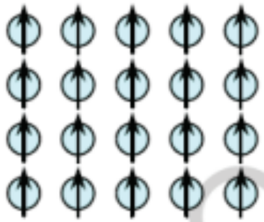
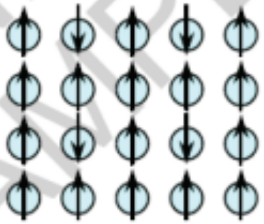
Metal			3*d*			4*s*
Sc	↑					⇅
Ti	↑	↑				⇅
V	↑	↑	↑			⇅
Cr	↑	↑	↑	↑	↑	↑
Mn	↑	↑	↑	↑	↑	⇅
Fe	⇅	↑	↑	↑	↑	⇅
Co	⇅	⇅	↑	↑	↑	⇅
Ni	⇅	⇅	⇅	↑	↑	⇅
Cu	⇅	⇅	⇅	⇅	⇅	↑

- Diamagnetism
- Anti Ferro-magnetism
- Ferro magnetism
- Paramagnetism
- Ferrimagnestism



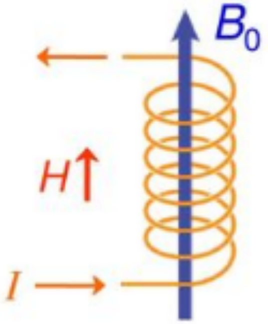
Fe_3O_4



Dia-magnetism		Atoms have no magnetic moment
Para-magnetism		Atoms have randomly oriented magnetic moments
Ferro-magnetism		Atoms have parallel aligned magnetic moments
Antiferro-magnetism		Atoms have anti-parallel aligned magnetic moments
Ferri-magnetism		Atoms have mixed parallel and anti-parallel aligned magnetic moments

Generation of a Magnetic Field -- Vacuum

- Created by current through a coil:



N = total number of turns
ℓ = length of each turn (m)
I = current (ampere)
H = applied magnetic field (ampere-turns/m)
B_0 = magnetic flux density in a vacuum (tesla)

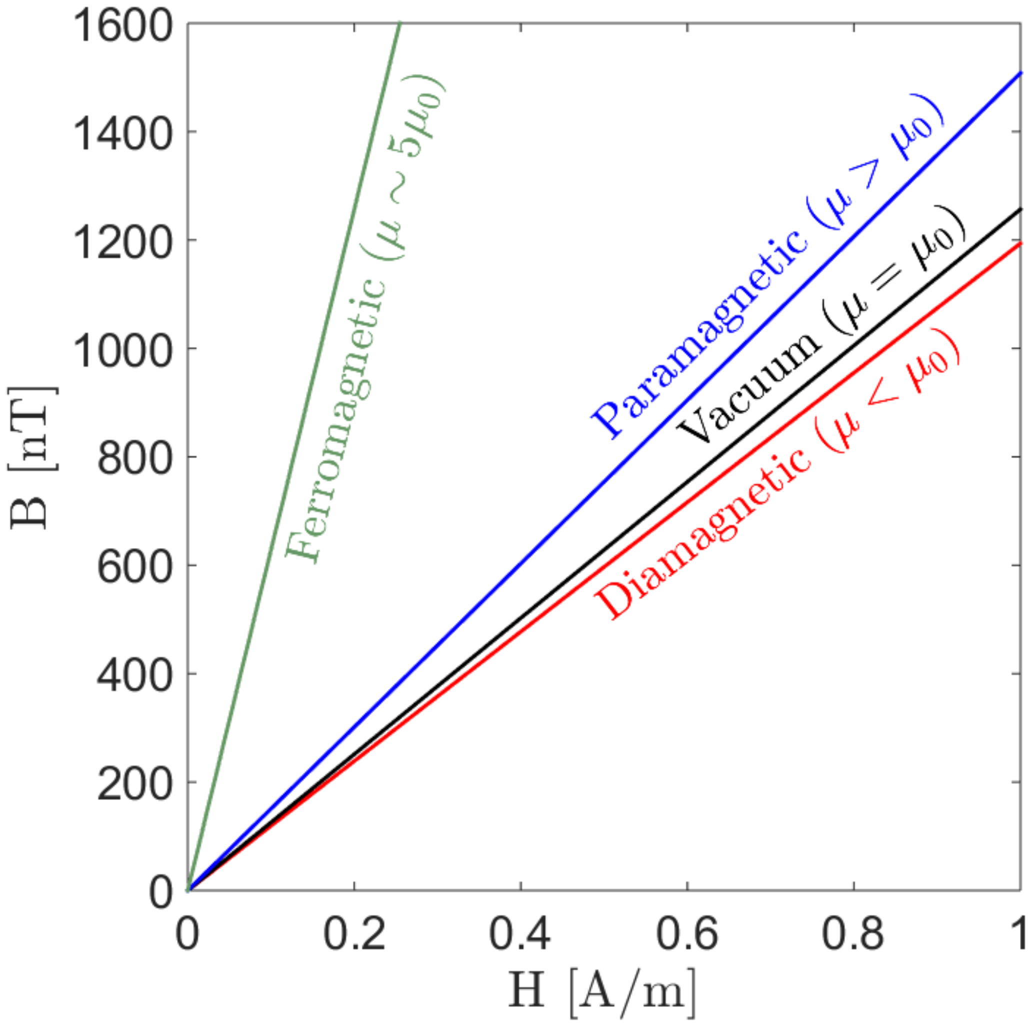
- Computation of the applied magnetic field, H:

$$H = \frac{NI}{\ell}$$

- Computation of the magnetic flux density in a vacuum, B_0:

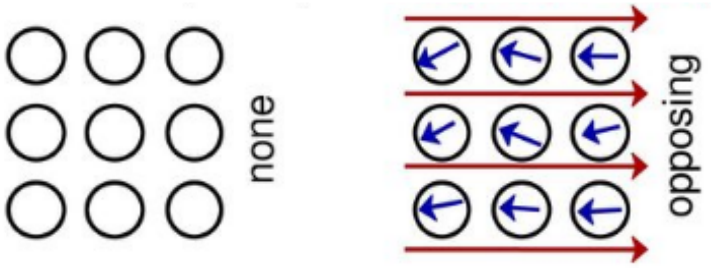
$$B_0 = \mu_0 H$$

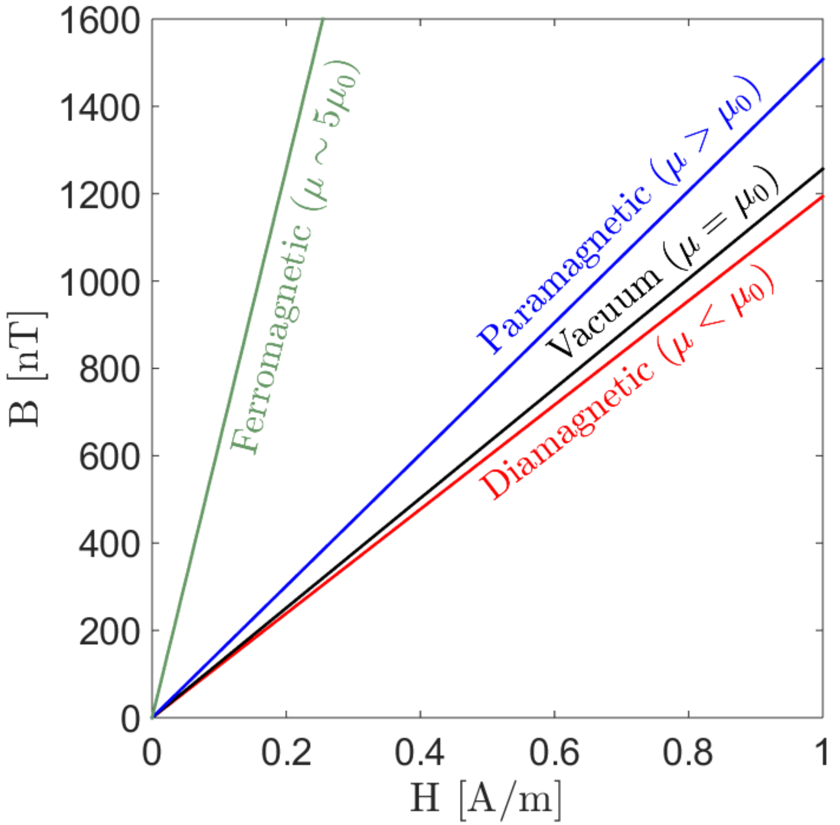
- $B = \mu H$
- Relative magnetic permeability $\mu_r = \frac{\mu}{\mu_0}$
- $B = \mu_0 H + \mu_0 M$
- The magnetic susceptibility m, which is the ratio between magnetization and the applied field, gives the amplification produced by the material $\chi_m = \frac{M}{H}$



Diamagnetic Behavior

- Dipoles oppose the magnetic field, causing the magnetization to be less than zero
- Materials such as copper, silver, silicon, gold, and alumina are diamagnetic at room temperature
- Superconductors are perfect diamagnets

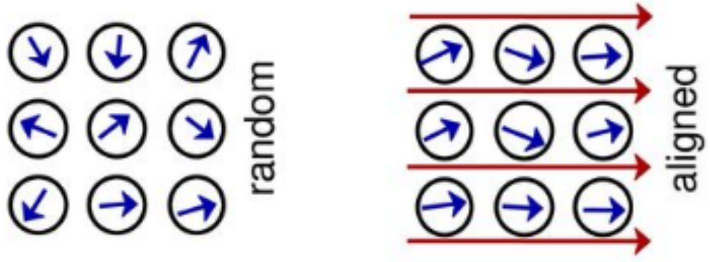


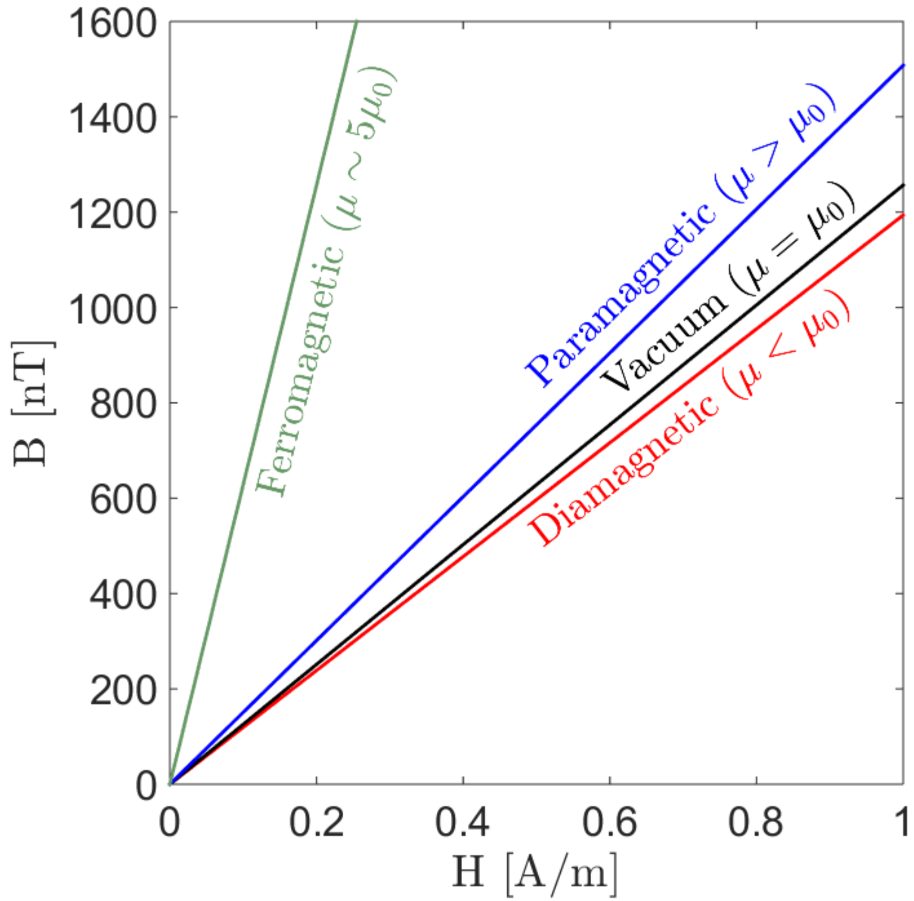


Pyrolytic Graphite

Paramagnetism

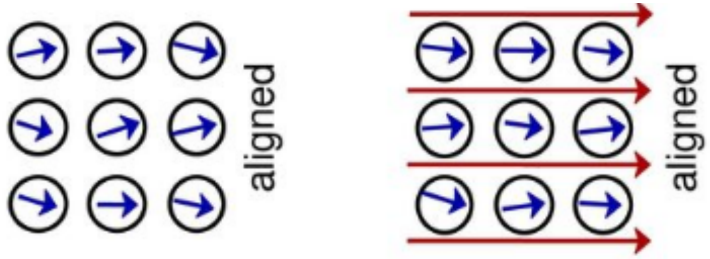
- Materials have unpaired electrons
- Net magnetic moment due to electron spin is associated with each atom
- The dipoles align with the field, causing a positive magnetization
- The effect is lost as soon as the magnetic field is removed
- Aluminum, titanium, and alloys of copper

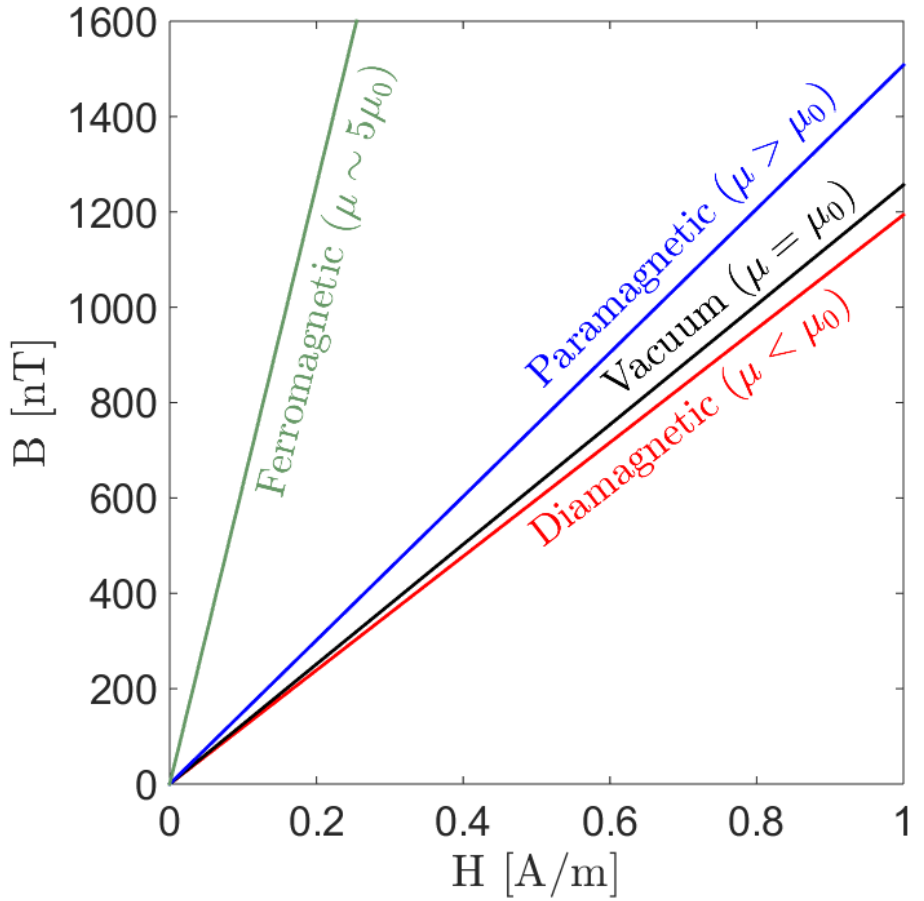




Ferromagnetism

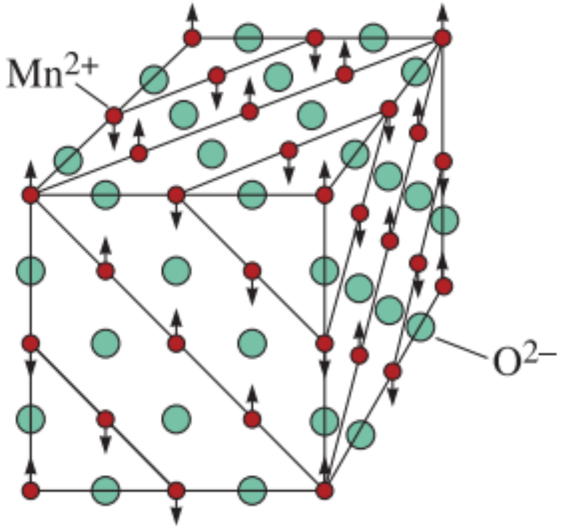
- Materials have unpaired electrons
- Net magnetic moment due to electron spin is associated with each atom
- The dipoles align <u>*easily*</u> with the field, causing a positive magnetization
- The effect is lost <u>*not*</u> as soon as the magnetic field is removed





Antiferromagnetism

- The magnetic moments produced in neighboring dipoles line up in opposition to one another in the magnetic field
- Zero magnetization
- Magnetic susceptibility is positive and small
- Manganese, chromium, MnO, and NiO

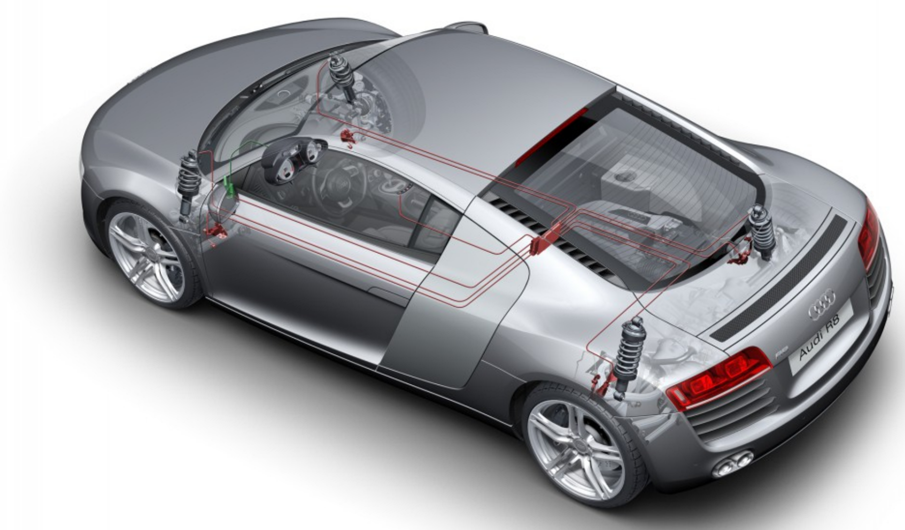


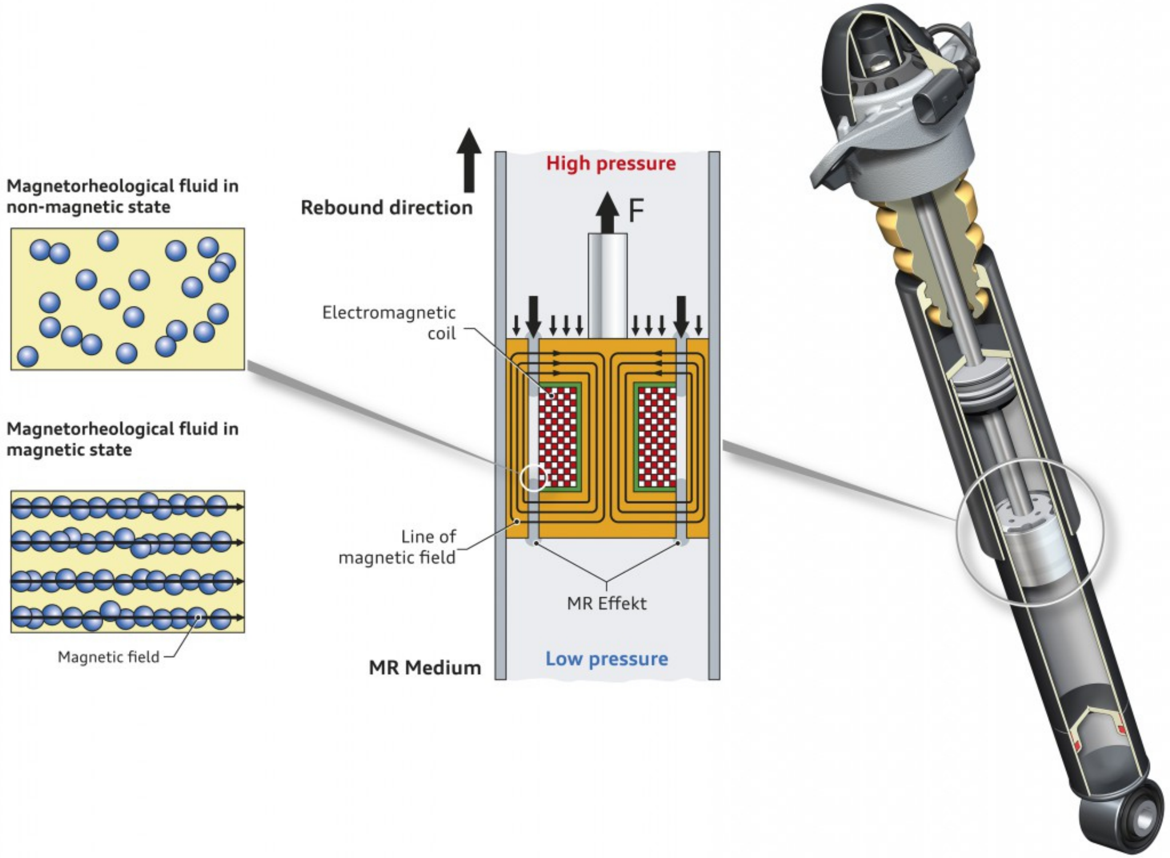
ferrimagnetism

- Incomplete cancelation of magnetic moments
- Mostly ceramics
- Very low eddy current loss
- Good magnetic field amplification

Superparamagnetism

- Ferro magnetic materials but behave like paramagnetic materials
- Fe3O4 → 5 nm toner
- Ferro fluid or liquid magnets
- Viscosity depends on magnetic field

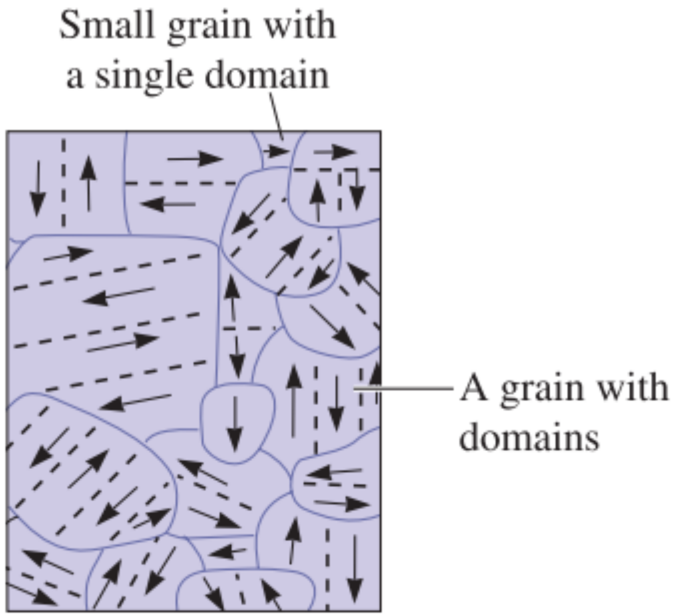


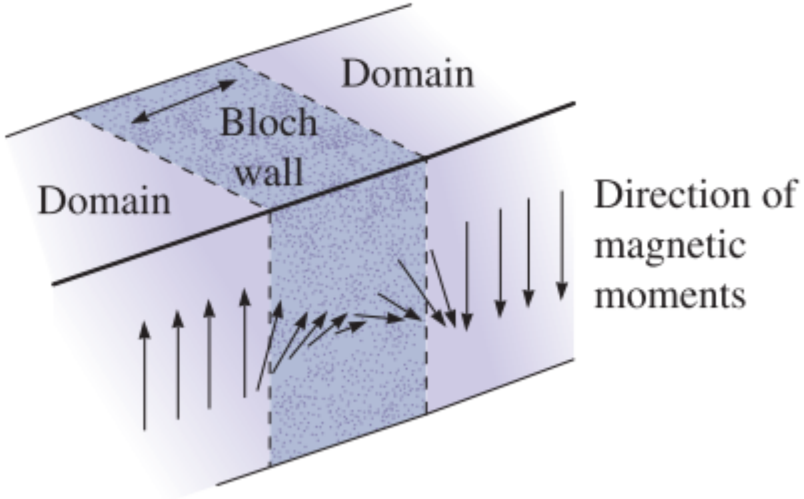


Magnetorheological fluid in non-magnetic state
Magnetorheological fluid in magnetic state
Magnetic field
Rebound direction
High pressure
F
Electromagnetic coil
Line of magnetic field
MR Effekt
MR Medium
Low pressure

Domain structure

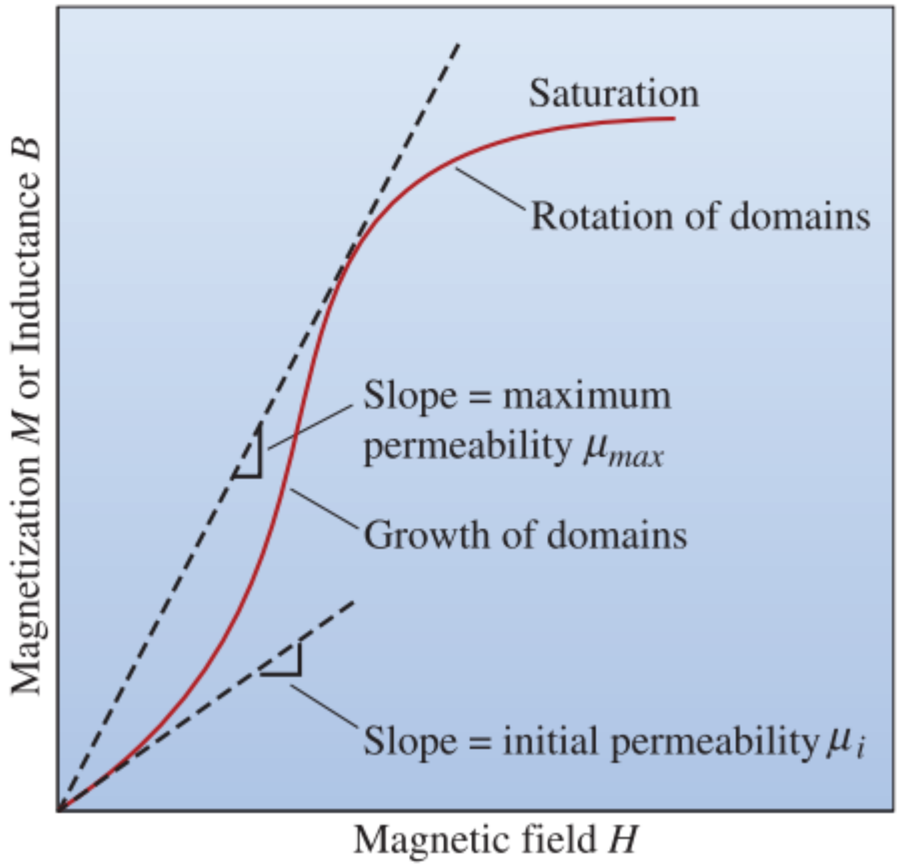
- Region where diploes are arranged in same direction
- Magnetization of ferromagnetic material = 0





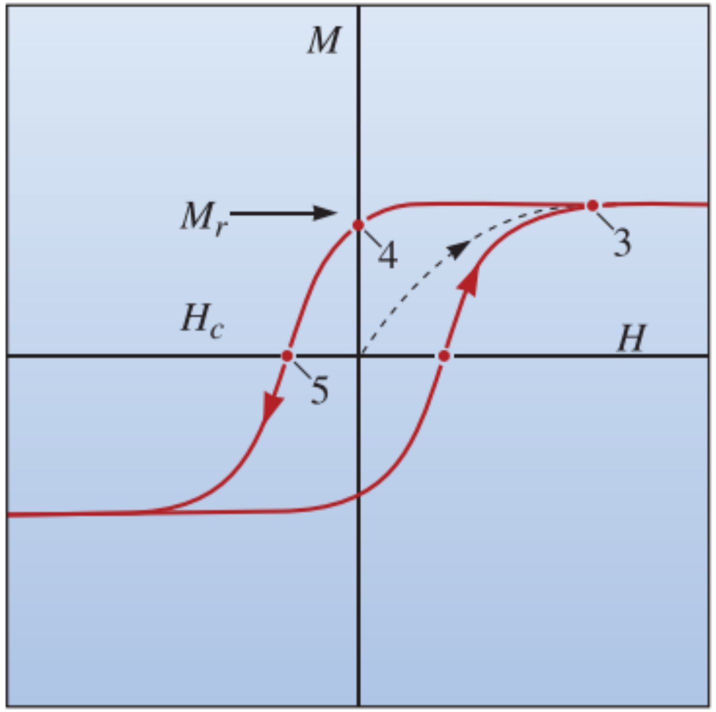
Domain growth and saturation

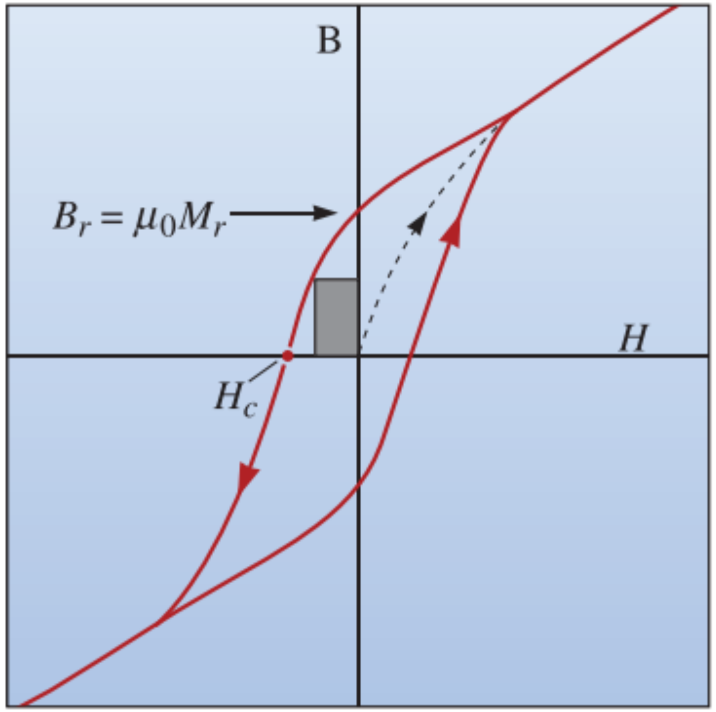
- Domains in favor of magnetic filed grows
- While other shrinks
- Rotation of domain



BH curve

- Some magnetization (M_r) is left after field is removed
- Retentivity (B_r)
- Magnetic field needed to bring magnetization to zero coercivity

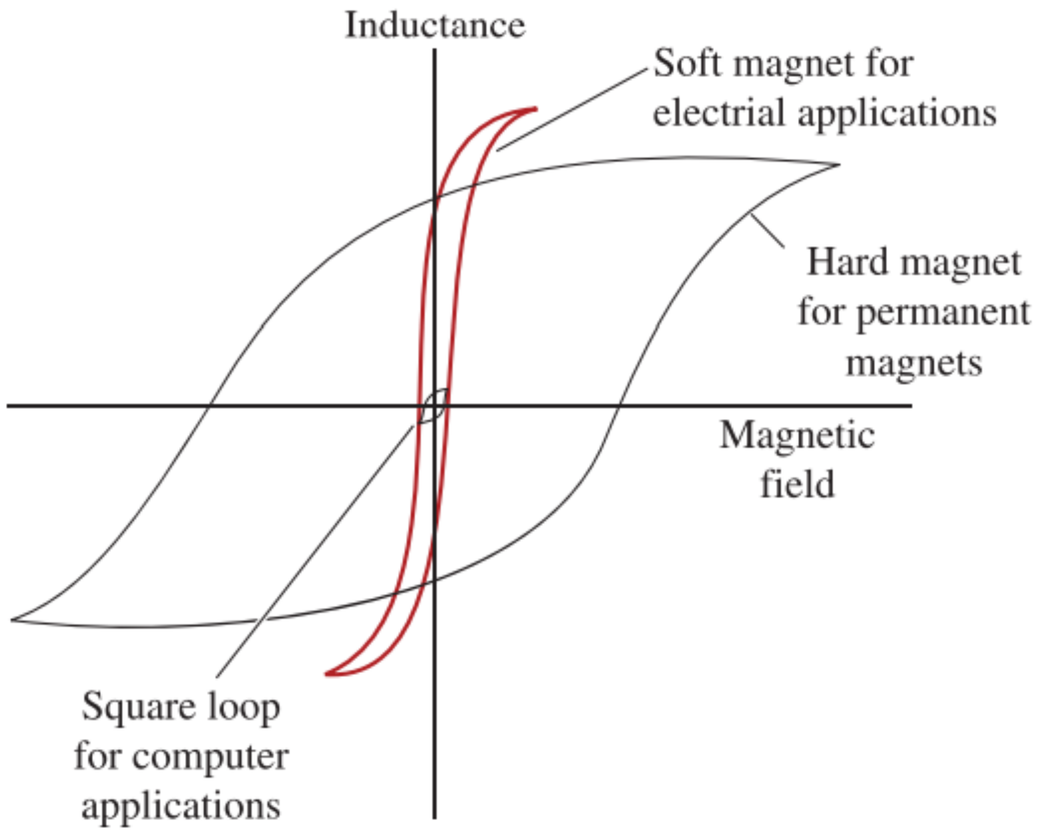




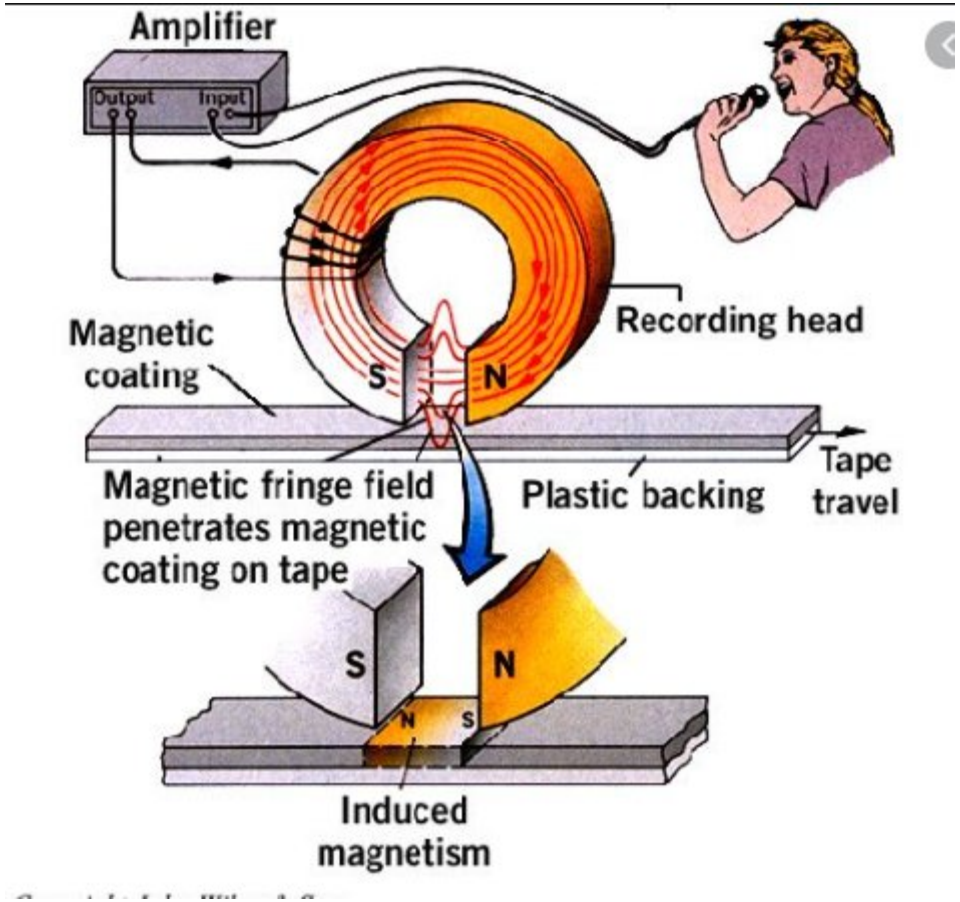
Soft, semi hard and hard magnets

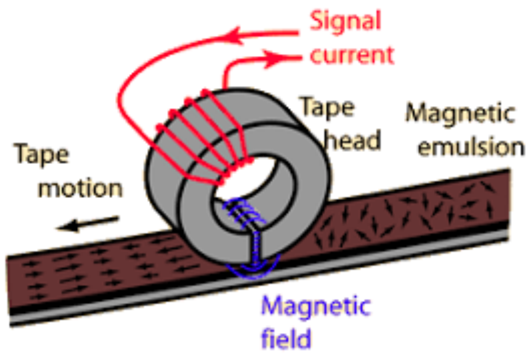
- Coercivity < 10^3 A/m →Soft
- Coercivity > 10^4 A/m → Hard

- Coercivity strongly depends or microstructure just like yield strength
- Magnetization is dependent on composition just like Young modulus

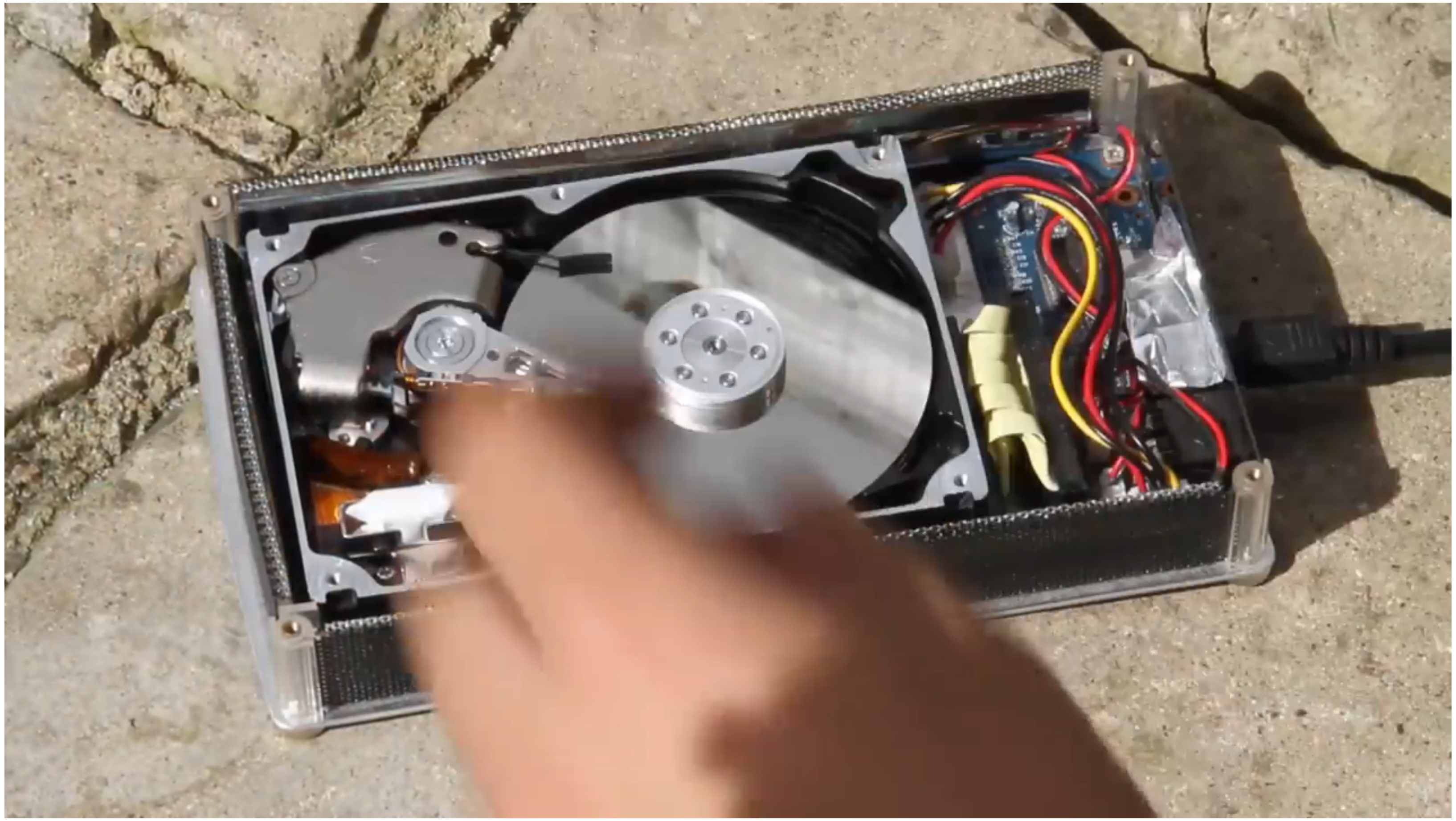


Data storage (semi-hard)



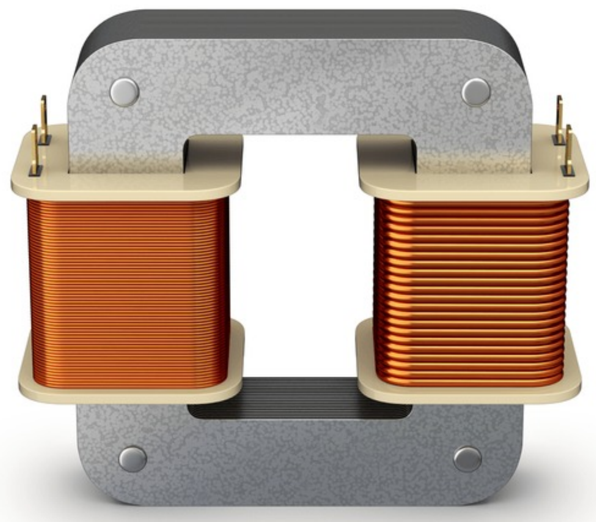


Data storage



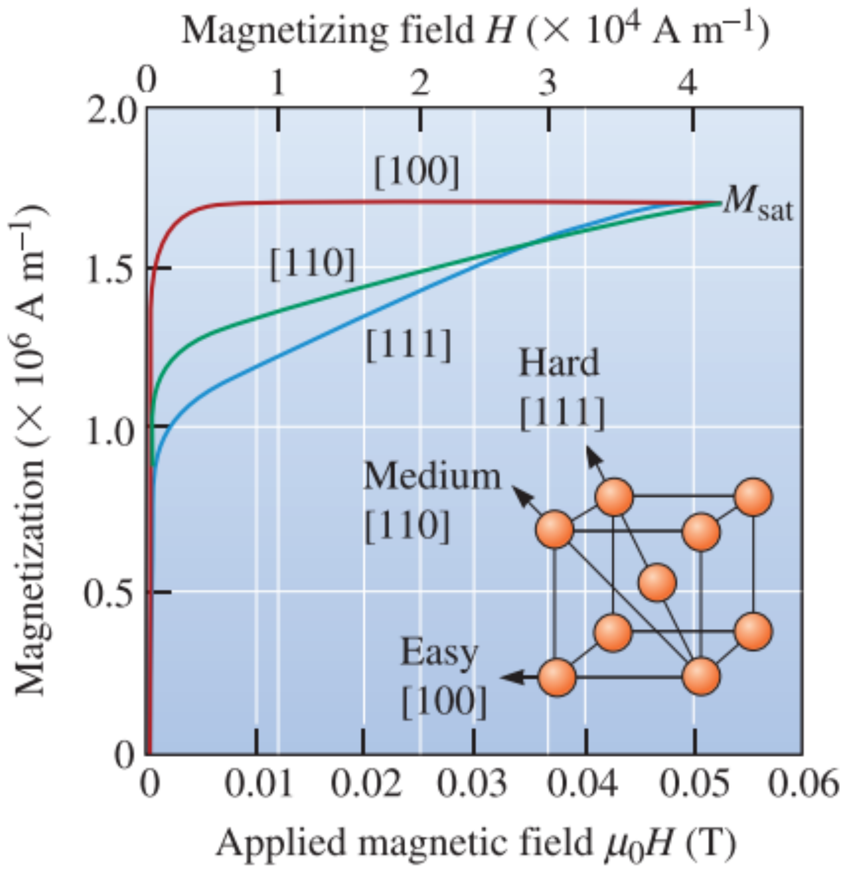
Soft Magnetic materials

- High magnetic permeability
- $Hc < 10^4\ Am^{-1}$
- High saturation magnetization



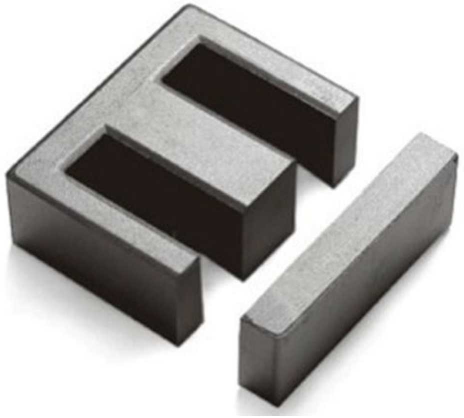
Losses in core

- Texture
- Laminate or composite



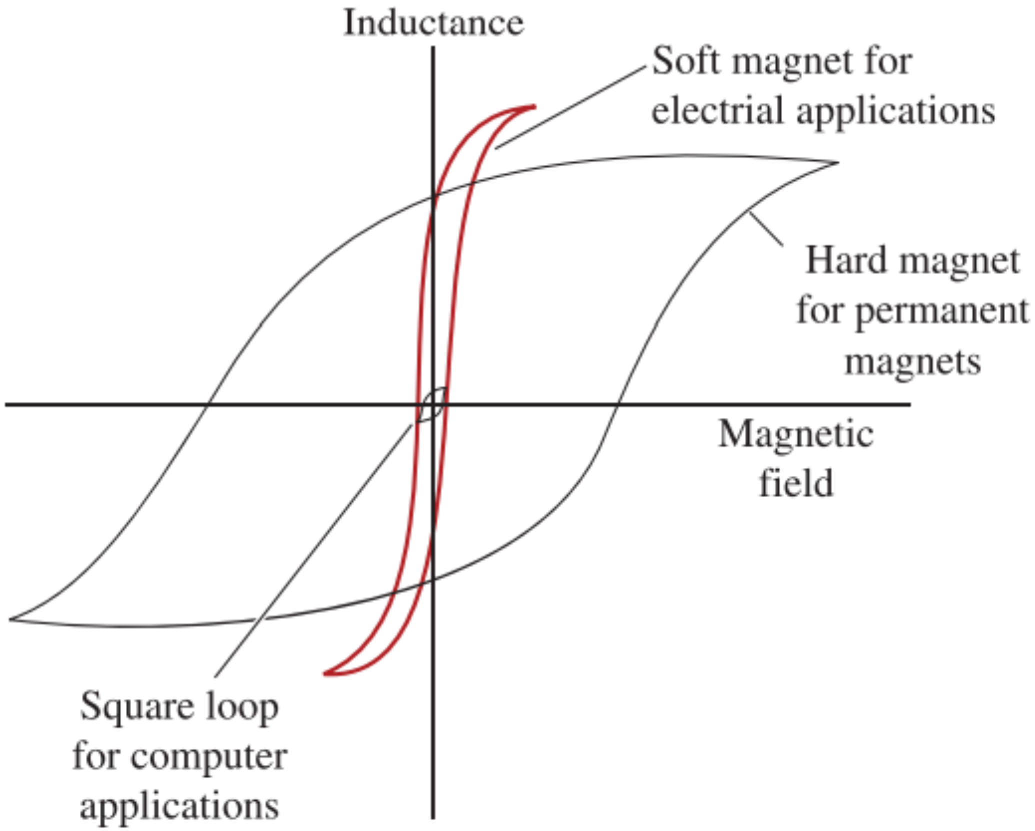
Switching mode power supply

- Higher frequency kHz to MHz
- Higher frequency → higher loss
- Eddy current loss

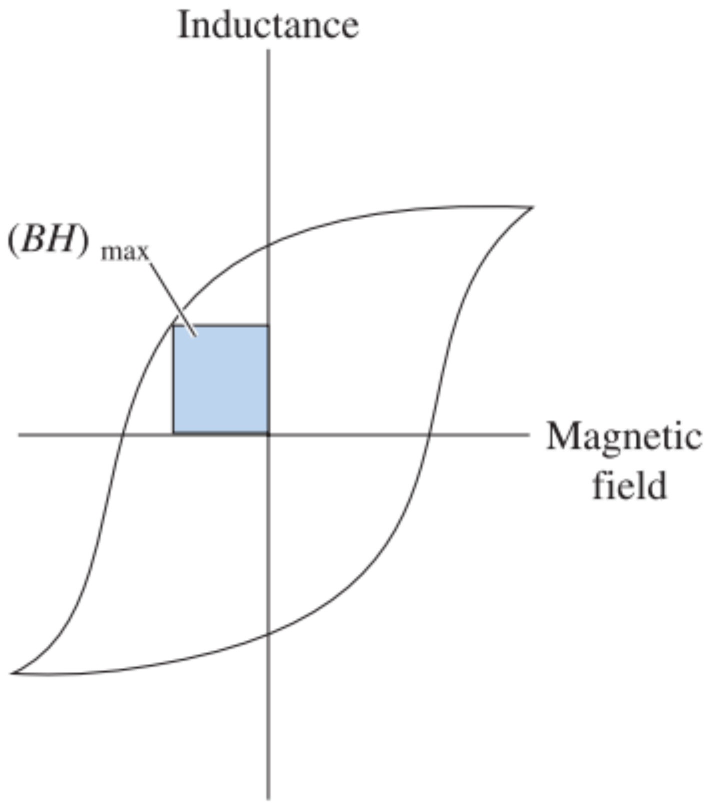


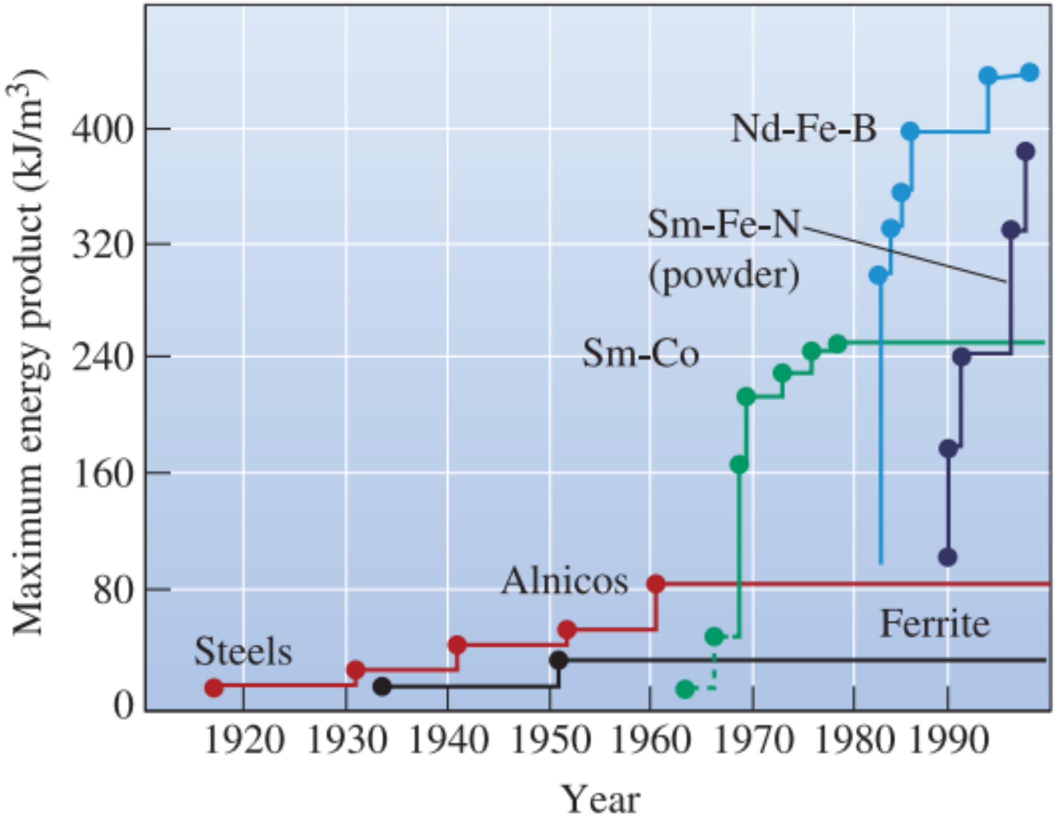
Hard magnets (permanent magnets)

- High remanance
- High permeability
- Large hysteresis loop
- High power (BH product)



Hard magnets



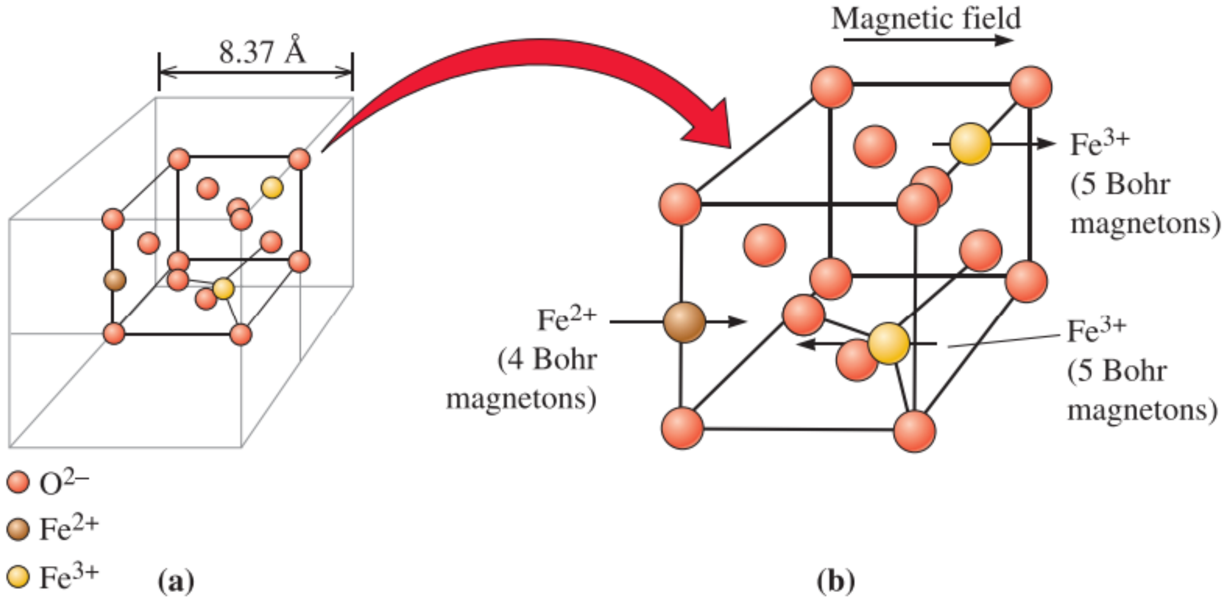


Hard magnets

- Select composition of high retentivity
- Improve structure for coercivity
- One domain per particle
- Alnico → precipitation of iron Co phase below 800C in magnetic field
- Co_5Sm → fine powder and sinter it magnetic field
- Neodymium magnet → $Nd_{12}Fe_{14}B + HfB_2$

Ferrites

- Broad family of magnetic materials
- Fe_3O_4 → Spinel structure
- Fe^{+2} → Mn, Zn, Ni or Cu → Soft Ferrites
- Fe^{+2} → Mg or Co →Semi-Soft Ferrites
- Yttria iron garnet → soft ferrite
- $SrFe_{12}O_{19}$ → hard magnets



Curie Temperature